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(54) **SCALABLE VERTICAL BUOYANT CABLE ANTENNA**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 183 days.

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(51) **Int. Cl.**
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H01Q 1/50 (2006.01)
H01Q 1/04 (2006.01)
H01Q 13/10 (2006.01)
H01Q 7/08 (2006.01)
H01Q 1/16 (2006.01)

(52) **U.S. Cl.**
CPC ***H01Q 1/34*** (2013.01); ***H01Q 1/04*** (2013.01); ***H01Q 1/50*** (2013.01); *H01Q 1/16* (2013.01); *H01Q 7/08* (2013.01); *H01Q 13/10* (2013.01)

(58) **Field of Classification Search**
USPC 343/709, 719
See application file for complete search history.

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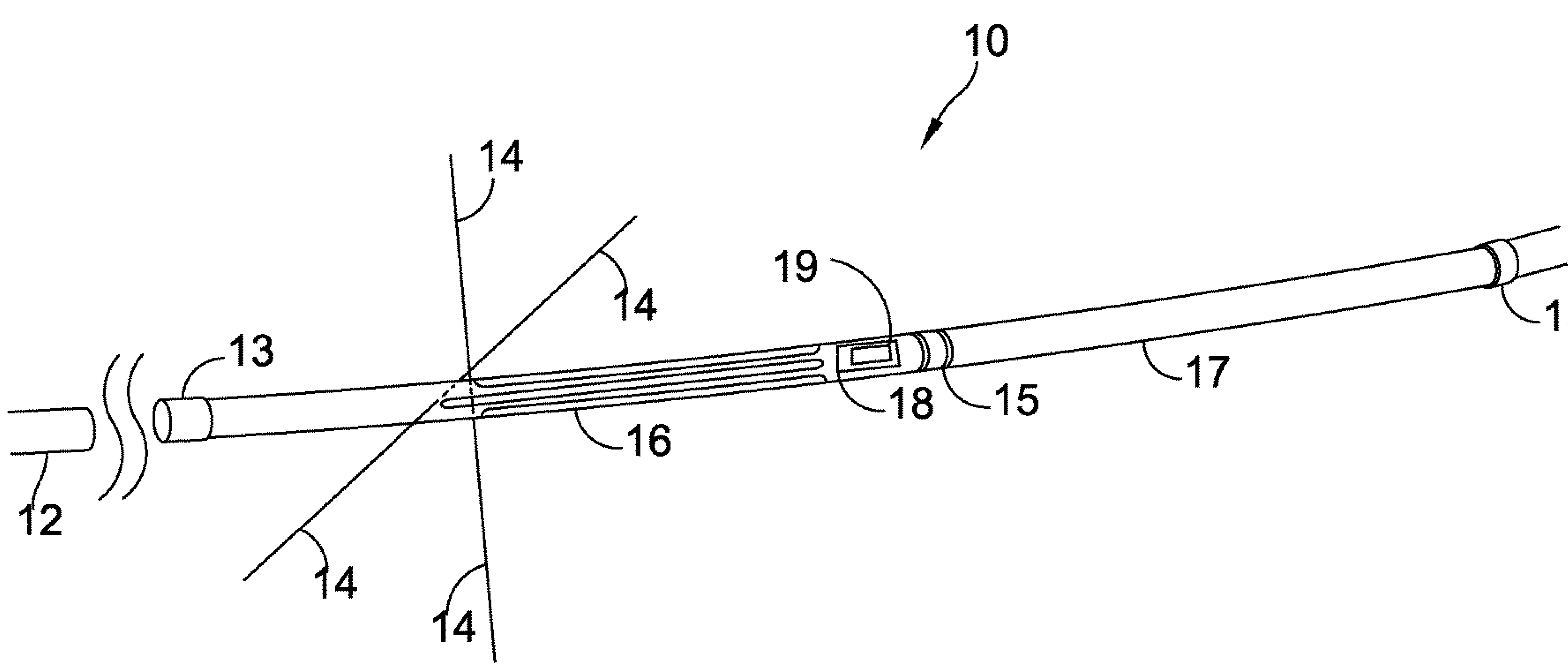
(57) **ABSTRACT**

The invention is a modular buoyant cable antenna that is towed on the surface of a body of water by a submerged underwater vehicle to allow communication coverage in an omnidirectional pattern that is also compatible with existing buoyant cable antenna deployment and retrieval systems. The antenna of the present invention comprises a floating cable having four identical antenna elements that are arranged in a cross configuration. The antenna uses the sea surface as a ground plane providing good antenna gain levels. The antenna is designed with an integrated impedance matching network to maximize radiation efficiency.

12 Claims, 4 Drawing Sheets



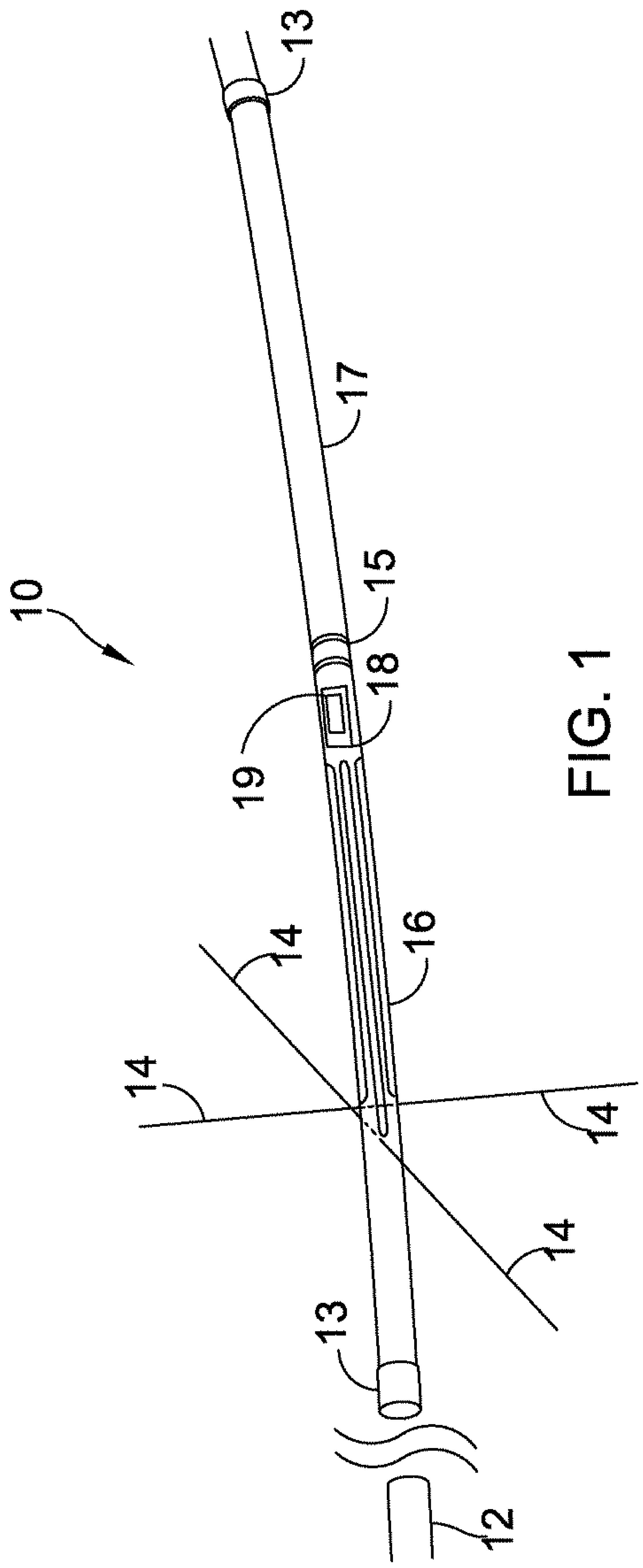


FIG. 1

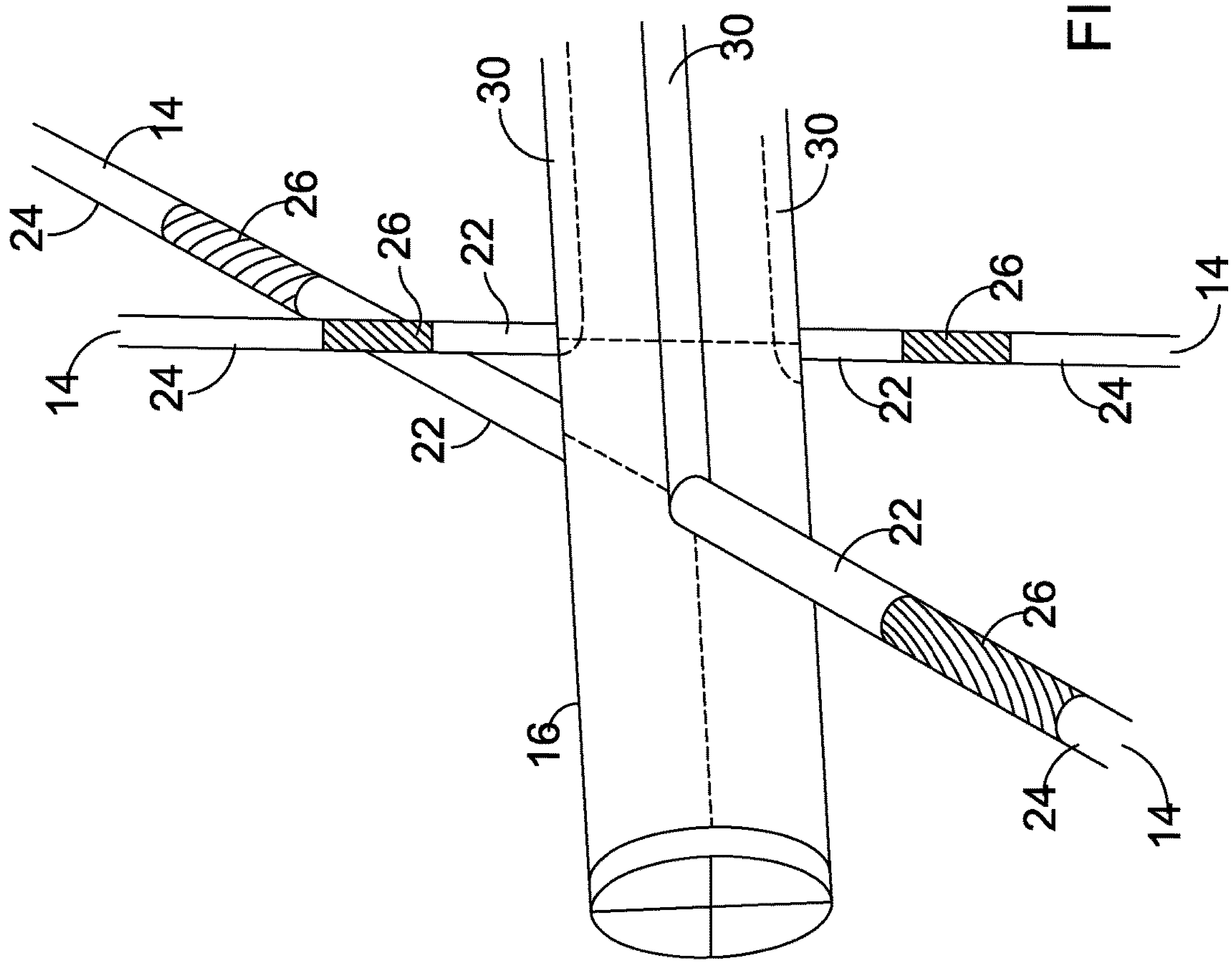


FIG. 2

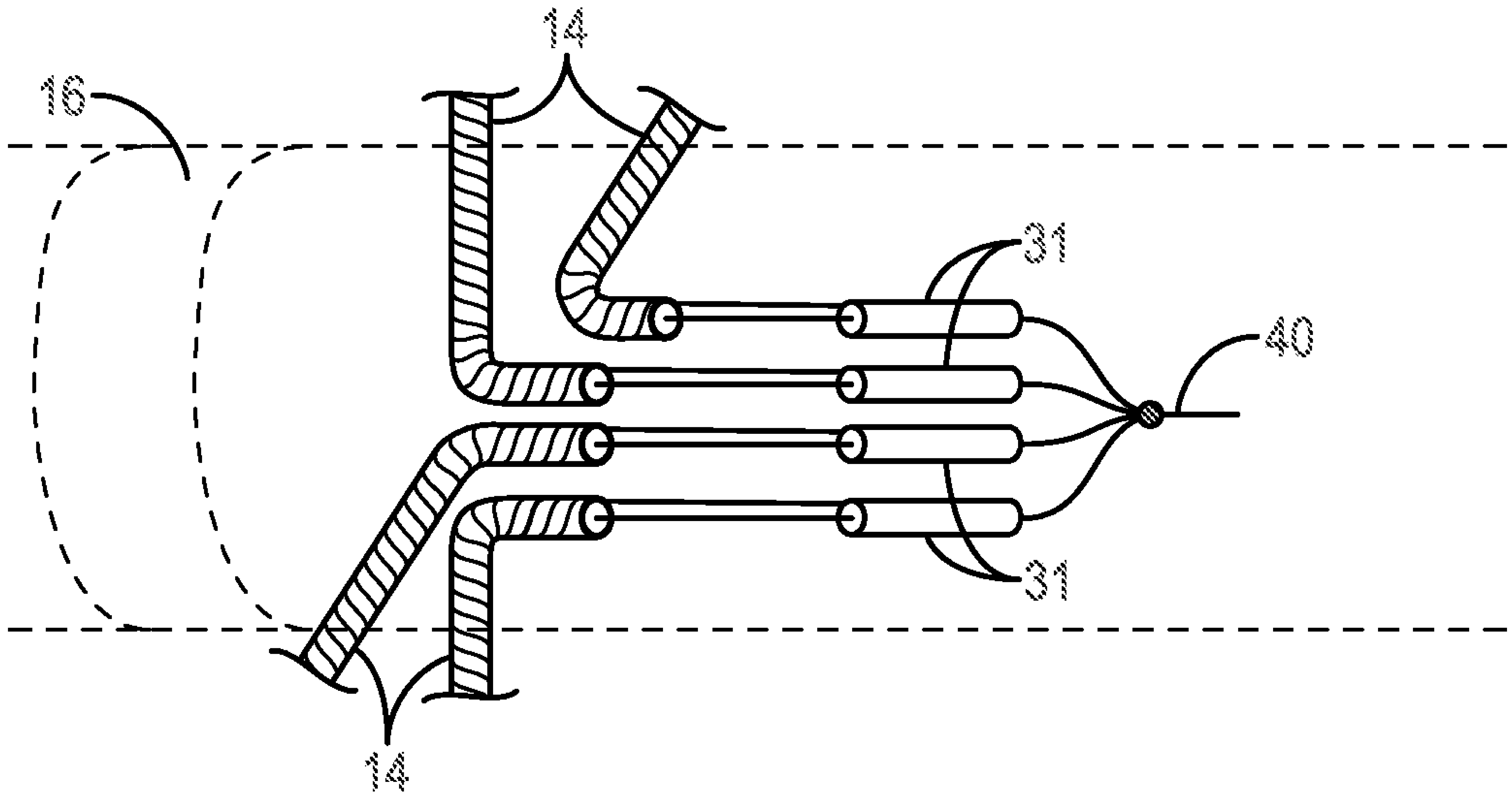


FIG. 3

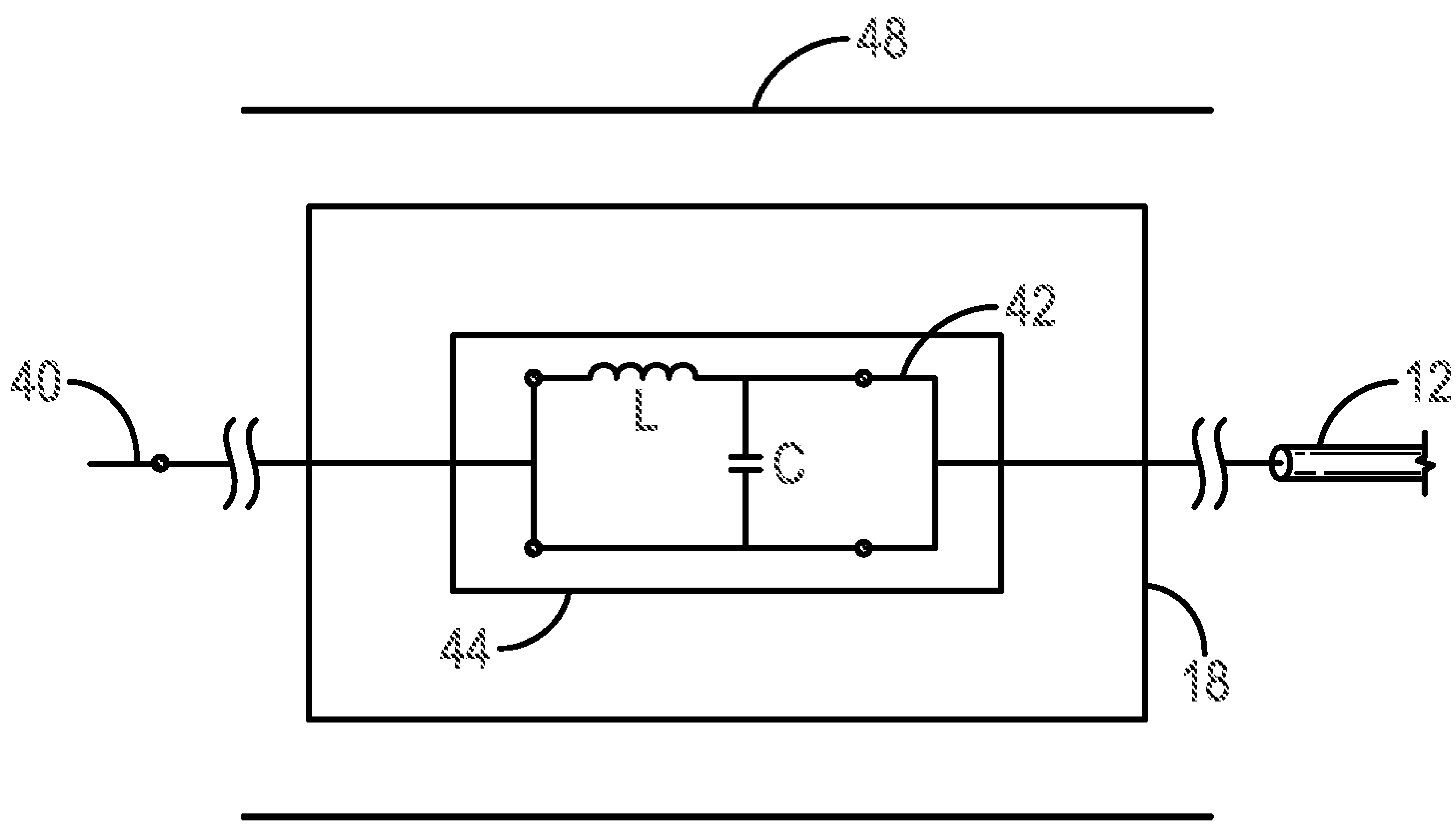


FIG. 4

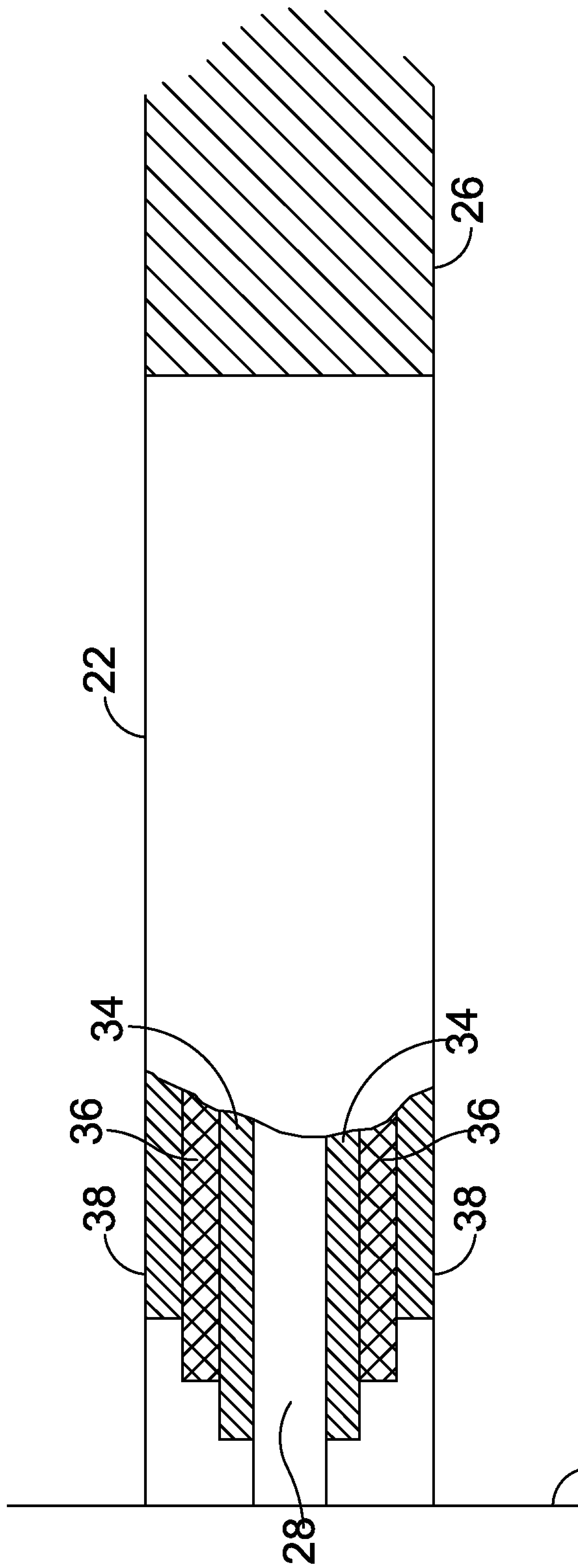


FIG. 5

SCALABLE VERTICAL BUOYANT CABLE ANTENNA

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefore.

CROSS REFERENCE TO OTHER RELATED APPLICATIONS

Not applicable.

BACKGROUND OF THE INVENTION

(1) Field of the Invention

The present invention relates to antennas for use with an underwater vehicle, and more specifically to a buoyant cable antenna that is towed by a submarine to allow communication coverage in an omni-azimuthal pattern in the Very High Frequency (VHF) frequency bands (30 MHz to 300 MHz) and can also be scaled to cover other frequency bands. This invention is specifically designed to be compatible with existing buoyant cable antenna deployment and retrieval systems.

(2) Description of the Prior Art

Radio frequency communication for submerged underwater vehicles is currently limited to a buoyant cable antenna (BCA) system. Currently, this communication system only provides unidirectional signal coverage, which is of limited utility. The effectiveness of radio frequency communication for underwater vehicles would be greatly increased if omni-azimuthal signal coverage was possible throughout a desired frequency range to limit communication gaps and avoid the necessity of maneuvering an underwater vehicle to establish a good communication link. What is needed is a new and improved buoyant cable antenna that can provide omni-azimuthal signal coverage in a desired frequency range.

SUMMARY OF THE INVENTION

It is a general purpose and object of the present invention to provide omni-azimuthal signal coverage for submerged underwater vehicles through the use of a buoyant cable antenna.

It is a further object to use a matching technique to provide a very high frequency antenna that uses the sea surface as a ground plane with reasonable gain levels above the noise floor.

It is another object of the invention to provide a modular and tunable mechanism to match the impedance of a four element buoyant cable antenna joined to a transmission line of an existing buoyant cable antenna system.

It is another object of the invention to have one vertical component of the buoyant cable antenna perpendicular to the ocean surface at all times.

These objects are accomplished through the use of a modular buoyant cable antenna with a vertical antenna component that eliminates signal null areas. The antenna of the present invention comprises a floating cable having four identical antenna elements that are arranged in a cross configuration where two of the four elements are directly aligned at one hundred eighty degrees in a first spatial plane and the other two elements are directly aligned at one hundred eighty degrees in a second spatial plane parallel to the first spatial plane such that each element is spaced ninety degrees apart from an adjacent element in the parallel spatial plane. The antenna elements are attached to and protrude from the floating cable. While floating on the water surface, the antenna may rotate freely with minimal signal loss with one antenna element always extended above and perpendicular to the water's surface. Omni-azimuthal coverage is achieved by the vertical posture of the antenna elements. The modular buoyant cable antenna of the present invention is specifically designed for compatible use with existing systems onboard underwater vehicles. As such the dimensions of the antenna (particularly the cross-sectional diameter) and the connectors comply with size and connection standards of existing systems. The antenna employs a tunable impedance matching network in a modular chassis to decrease the reflections and increase the radiation properties between the transmission line and the antenna.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features and advantages of the present invention will become apparent upon reference to the following description of the preferred embodiments and to the drawings, wherein corresponding reference characters indicate corresponding parts throughout the several views of the drawings and wherein:

FIG. **1** illustrates the exterior structure of the modular buoyant cable antenna of the present invention;

FIG. **2** illustrates the connection of the antenna elements to the encapsulating cylindrical encasement;

FIG. **3**, illustrates the connection configuration of the ends of all four antenna elements electrically connected within the encasement at a single connection point;

FIG. **4**, illustrates the a tunable matching network; and

FIG. **5** illustrates the flexible shielded first section of the antenna elements.

DETAILED DESCRIPTION OF THE INVENTION

Referring to FIG. **1**, the present invention teaches a modular buoyant cable antenna **10** that is attached to an underwater vehicle via a transmission line **12** and is aligned with an arrangement of existing buoyant cable antenna system components (not shown). The antenna **10** is electrically connected to transmission line **12** through connectors **13** that are compliant with the standards of the existing buoyant cable antenna system. The antenna **10** is towed by a submerged underwater vehicle as the antenna **10** floats on the surface of the water. The antenna **10** is composed of four sections; an encapsulating cylindrical encasement **16**, a modular chassis **18** containing a tunable impedance matching network **19**, a buoyant section **17** comprising a cable made of polyethylene foam that provides the buoyancy in seawater, and four identical antenna elements **14** that are attached to and protrude from encasement **16**.

In a preferred embodiment, encasement **16** is made from a potting compound such as a thermo-setting plastic or a silicone rubber gel that is water tight, flexible, tear resistant and meets the tensile requirements for towing a buoyant cable antenna at specified speeds as well as deployment and retrieval by existing cable antenna systems. In a preferred embodiment the potting compound that comprises encasement **16** is the commercially available PR-1592 manufactured by PPG Aerospace Inc. In a preferred embodiment encasement **16** encapsulates the electronic components (not shown) of the antenna **10**. In a preferred embodiment buoyant section **17** is a cable made of polyethylene foam that provides the buoyancy in seawater. Encasement **16** is joined to buoyant section **17** by means of a rubber coupler **15** that allows easier bonding between the potting compound of encasement **16** and the polyethylene of buoyant section **17**. In a preferred embodiment the diameter of encasement **16** and buoyant section **17** is 0.65 inch allowing them to conform to the required dimensions of existing cable antenna systems currently in use in underwater vehicles.

Referring to FIG. **2**, the antenna elements **14** are held in place by the potting compound of encasement **16**. The four identical antenna elements **14** are arranged symmetrically around the encasement **16** in a cross configuration where two elements **14** are directly aligned at one hundred eighty degrees in a first spatial plane and the other two elements are directly aligned at one hundred eighty degrees in a second spatial plane parallel to the first spatial plane such that each element **14** is perpendicular to an adjacent element **14** in the parallel spatial plane. In operation, at least one element **14** is extended vertically above and perpendicular to the water surface when the antenna **10** is deployed regardless of rotations even as the antenna **10** moves along the surface of the water.

Each antenna element **14** is fabricated in sections from different materials. The first section **22** that is attached to the encasement **16** is fabricated using the alloy Nitinol, which has the physical property of high elasticity. The second section **24** is fabricated using carbon fiber, which has the physical properties of rigidity, corrosion resistance and sufficient electrical conductivity as needed for radio frequency communication. In a preferred embodiment the first section **22** protrude one inch from the encasement and the second section **24** is a quarter wave in length at a desired operational frequency plus five extra inches. The two sections **22** and **24** are joined through a mechanical and electrical crimp connection **26**. Whereas the carbon fiber increases stiffness for improved towing posture, the Nitinol allows the four antenna elements **14** to bend and fold against the sides of the encasement **16** when the antenna is not deployed. When bent and folded against the encasement **16**, the four antenna elements **14** are nested in machined grooves **30** in the encasement **16** such that the overall cross-sectional diameter of the modular section does not exceed the diameter of the encasement **16**. In a preferred embodiment, the diameter of the encasement **16** is 0.65 inch allowing it to conform to the required dimensions of existing buoyant cable antenna systems.

Referring to FIG. **3**, the ends of all four antenna elements **14** are electrically connected within the encasement **16** at a single connection point **40** through transmission lines **31**. The connection configuration is illustrated in FIG. **3**. Connecting the elements **14** facilitates impedance matching the antenna, a necessary process to avoid energy reflection, and to promote more efficient antenna radiation.

Referring to FIG. **4**, there is illustrated an exemplary tunable matching network **42** for impedance matching the antenna **10**. The components of the matching network **42** as illustrated represents a single embodiment using a capacitor C and inductor L, however, other embodiments may also be suitable depending on the impedance of the transmission line **12**. Matching network **42** is electrically connected to the elements **14** after connection point **40**. The implementation of matching network **42** within antenna **10** is intended to match the impedance of the elements **14** with the impedance of the transmission line **12** in order to reduce the reflections between the transmission line **12** and the antenna **10**.

Matching network **42** is designed to allow modification/substitution of its internal electrical components in order to tune the antenna **10** to a specific frequency. In a preferred embodiment, the network **42** is designed on a removable circuit board **44** and placed in a modular chassis **18** that is then placed in a water proof housing **48** that is joined to encasement **16** and buoyant section **17**.

As illustrated in FIG. **5**, for each antenna element **14**, the first section **22** is shielded. In a preferred embodiment the first section **22** is six inches long. The Nitinol **28** is covered by a layer **34** of insulating material. Disposed over the layer **34** of insulating material is a braid **36** of conductive material. The braid **36** is covered by an outer layer **38** of insulating material. The braid **36** is electrically connected to the ground in the antenna system (not shown). The arrangement of layer **34** covered by braid **36** covered by outer layer **38** combines to create a coaxial cable for the first section **22** of each antenna element **14**. The coaxial cable design provides shielding to protect the antenna **10** from signal dropout, which can occur when the plane of the sea water rises on the antenna elements of an unshielded antenna.

The advantages of the present invention are that the antenna **10** allows communication coverage in an omni-azimuthal pattern. The modular buoyant cable antenna **10** is compatible with existing buoyant cable antenna systems due to its dimensions and its use of standard connectors. This allows users to quickly add, remove, or interchange the antenna **10** with existing buoyant cable antenna systems. An advantage of the integrated impedance matching network is that even if the antenna elements rotate while the antenna is deployed causing the elements to change position the matching network continues to perform its function so long as one element remains above the water surface. The simplicity of the impedance matching network allows modification of the components in order to tune the antenna to a wide range of frequencies.

In light of the above, it is therefore understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A modular buoyant cable antenna for use with an underwater vehicle comprising:

an encapsulating cylindrical encasement joined to an underwater vehicle via a transmission line, wherein the encasement is made from a potting compound that encapsulates a plurality of electronic components of the antenna;

a buoyant section joined to said encapsulating cylindrical encasement, wherein the buoyant section is a cable made of polyethylene foam that provides buoyancy in seawater;

four identical antenna elements that are attached to and protrude from said encapsulating cylindrical encasement wherein the four identical antenna elements are arranged symmetrically around the encasement in a cross configuration where two elements are directly aligned at one hundred eighty degrees in a first spatial plane and the other two elements are directly aligned at one hundred eighty degrees in a second spatial plane parallel to the first spatial plane such that each element is perpendicular to an adjacent element in the adjacent parallel spatial plane, wherein in operation at least one element is extended vertically above and perpendicular to a water surface when the antenna is deployed regardless of the encasement rotations as the antenna moves along the surface of the water, wherein the four antenna elements are designed to bend and fold against the sides of the encasement when the antenna is not deployed such that when bent and folded against the encasement the four antenna elements are nested in grooves that are molded in the encasement and machined in the buoyant section, such that the overall cross-sectional diameter of the antenna remains constant when the four antenna elements are folded into the grooves, wherein each of the four antenna elements are electrically connected within the encasement to the transmission line at a single connection point;

a tunable impedance matching network for impedance matching the antenna, wherein said matching network is electrically connected to the four antenna elements after the single connection point;

wherein the design and dimensions of the modular buoyant cable antenna allow it to float on the surface of a body of water while being towed by an underwater vehicle to be deployed and retrieved by an existing cable antenna deployment and retrieval system;

wherein each antenna element is fabricated in sections from different materials comprising:

a first section that is attached to the encasement being fabricated from the alloy Nitinol, which has the physical property of high elasticity allowing the four antenna elements to bend and fold against the sides of the encasement when the antenna is not deployed;

a second section being fabricated from carbon fiber, which has the physical property of rigidity for improved towing posture, corrosion resistance and sufficient electrical conductivity as needed for radio frequency communication; and

a mechanical and electrical crimp connection that joins the first section to the second section.

2. The antenna of claim **1** wherein for each antenna element the first section fabricated from Nitinol is shielded by an arrangement of layers comprising:

a first layer of insulating material disposed over the first section;

a braid of conductive material disposed over the layer of insulating material, wherein the braid is electrically connected to the ground of the antenna system;

an outer layer of insulating material disposed over the braid of conductive material; and

wherein the arrangement of the first layer of insulating material covered by the braid of conductive material covered by the outer layer of insulating material combines to create a coaxial cable for the first section of each antenna element which provides shielding to protect the antenna from signal dropout.

3. The antenna of claim **1** wherein the potting compound is a thermo-setting plastic that is water tight, flexible, tear resistant and meets the tensile requirements for deployment and retrieval of a buoyant cable antenna in an existing cable antenna deployment and retrieval system.

4. The antenna of claim **1** further comprising connectors that are compliant with the standards of existing buoyant cable antenna systems that connect the antenna to the transmission line.

5. The antenna of claim **1** wherein the potting compound that comprises the encapsulating cylindrical encasement is PR-1592 manufactured by PPG Aerospace Inc.

6. The antenna of claim **1** wherein the encapsulating cylindrical encasement is joined to the buoyant section by means of a rubber coupler that allows easier bonding between the potting compound of the encapsulating cylindrical encasement and the polyethylene of the buoyant section.

7. The antenna of claim **1** wherein the diameter of encasement **16** and buoyant section **17** is 0.65 inch allowing them to conform to the required dimensions of an existing cable antenna deployment and retrieval system.

8. The antenna of claim **1** wherein the second section of each of the four antenna elements is a quarter wave in length at a desired operational frequency.

9. The antenna of claim **1** wherein the matching network is joined in series with an antenna circuit, wherein the implementation of the matching network within the antenna matches the impedance of the four antenna elements to reduce the reflections between the transmission line and the antenna, wherein the matching network increases the radiation efficiency of the antenna.

10. The antenna of claim **9** wherein the matching network is fabricated on a removable circuit board designed to allow modification and substitution of its internal electrical components in order to tune the antenna to a specific frequency in a different desired frequency.

11. The antenna of claim **10** further comprising

a modular chassis that contains the matching network circuit board; and

a water proof housing that surrounds the modular chassis and is joined to the encapsulating cylindrical encasement and buoyant section.

12. The antenna of claim **1** wherein a length of the transmission line is such that the impedance of the four antenna elements together moves along a smith chart to a point that provides matching with a plurality of electrical components.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 9,705,186 B1
APPLICATION NO. : 14/684487
DATED : July 11, 2017
INVENTOR(S) : Pablo Lozada-Ortiz et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page

Item (74), change attorney name from “James M. Kasiachke” to --James M. Kasischke--.

Signed and Sealed this
Twenty-second Day of August, 2017

Joseph Matal

Performing the Functions and Duties of the
Under Secretary of Commerce for Intellectual Property and
Director of the United States Patent and Trademark Office